Biodiesel and the Environment

An innovative collaboration linking science and policy

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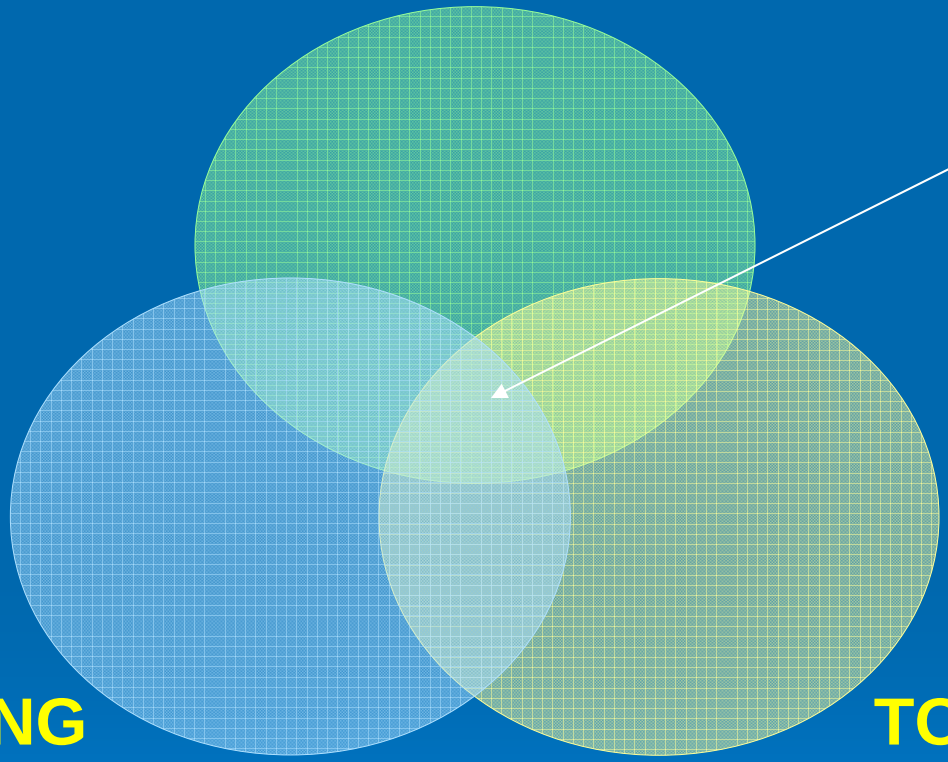
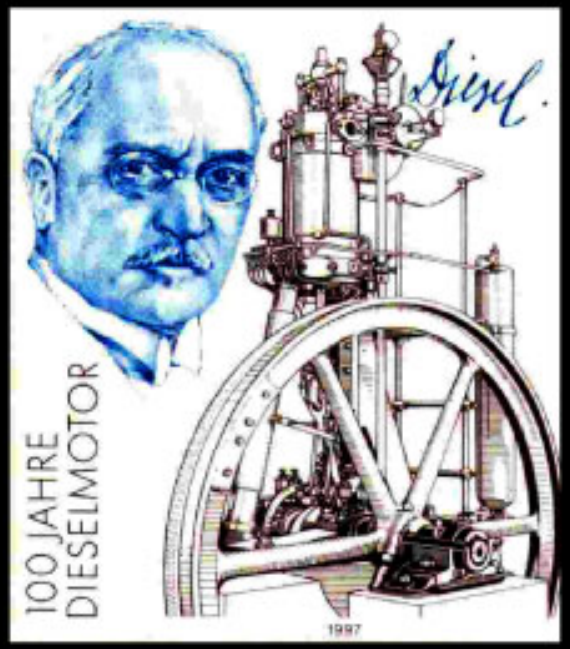
NATIONAL DECISION-MAKING & POLICY

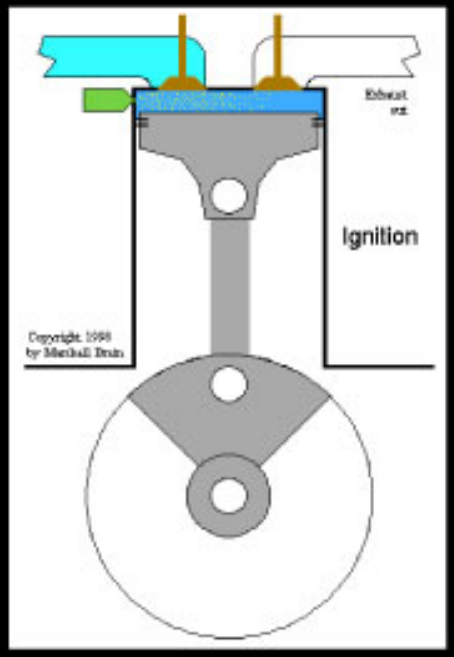


Rudolf C. K. Diesel

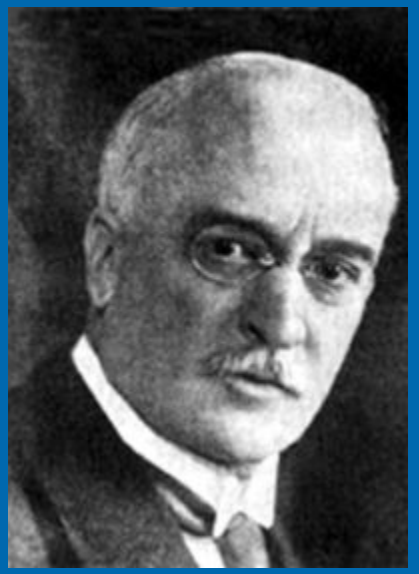
- Famous German inventor
- Known for inventing the Diesel Engine

Rudolf Diesel invented the diesel to run on vegetable oil over 100 years ago





Rudolf C. K. Diesel



"the use of vegetable oils for engine fuels may seem insignificant today but such oils may become, in the course of time, as important as petroleum and the coal-tar products of the present time." - 1912 speech, Rudolf Diesel

Two thirds of all petroleum used in the U.S. is used in transportation.

http://www.epa.gov/NE/eco/diesel/

2002: The US consumed 20 million barrels per day
**** spending $475,000 per minute on foreign oil ****

What are the challenges for Diesel Engines??

What led to 2007/2014 Standards for Diesel Engines and Fuels?

What is Keene State's Role in these national efforts???

Diesel Fuel

Many desirable qualities:

Efficient fuel,

Effective fuel/technology,

Available fuel,

Current system established….economic impact

- Increasing concerns regarding health and environmental impacts of diesel equipment

- Increasing awareness of the emissions contribution to pollutants of concern from diesel engines

Critical Events/Study

- 1999: California study---MATES I and II—and regulation

- 2000: USEPA finalizes Diesel Health Assessment Document

- 2000 – current day: Non-road and on-road emissions and exposure analyses

- 2006: USEPA tightens the national ambient air quality standard for fine particulate matter

The Major Health Concerns with Diesel:

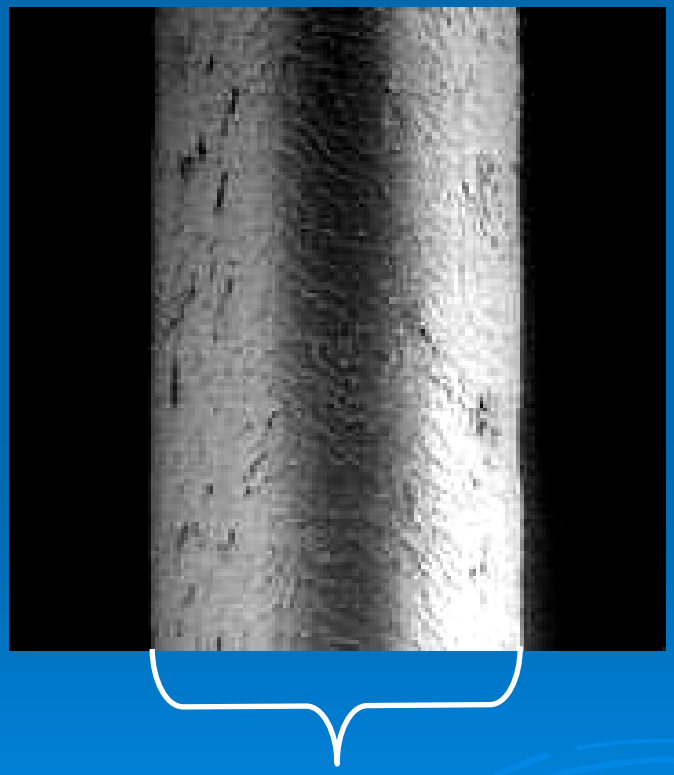
- *Fine and Ultrafine Particulate Matter*
- *Volatile and semi-volatile organic compounds*
- *Cancer causing mixture?*

Major Environmental Concerns:

- *NOx*
- *Volatile organic compounds*

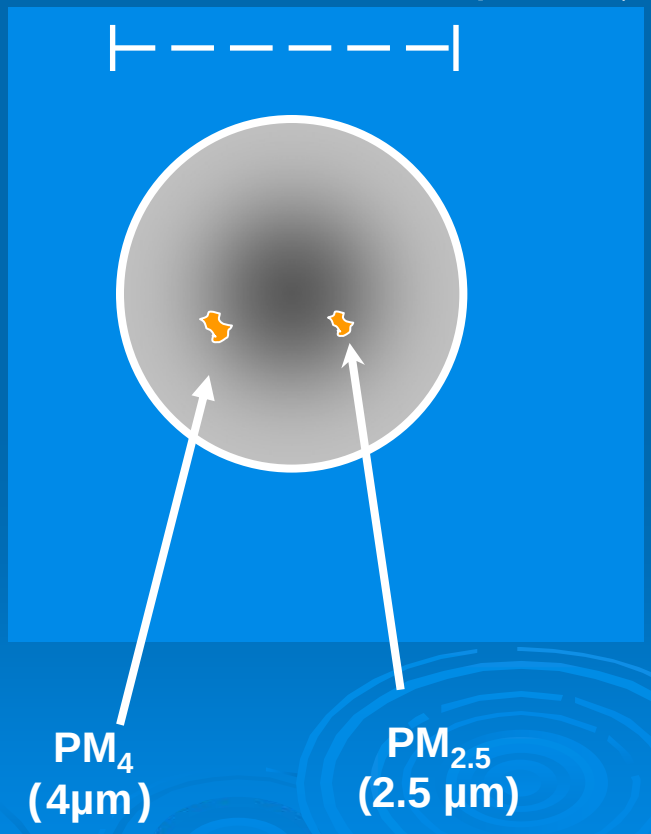
What are Fine and Ultrafine Particles?

A complex mixture of extremely small solid particles and drops of liquid in the air



Human Hair (45 - 130 µm diameter)

Hair cross section (~100 µm)



M. Lipsett, California Office of Environmental Health Hazard Assessment

Potential Health Impacts linked to diesel:

Ozone, fine particles, toxic compounds from diesel engines can cause or exacerbate:

- Asthma;
- Chronic bronchitis;
- Chronic obstructive airway disease;
- Cardio-pulmonary morbidity and mortality;
- Cancer… “highly likely to cause cancer in humans”
- 40 known or suspected cancer causing agents in the exhaust mixture….

Fuels and Air Quality

Motor vehicles in the Northeast:

- Emit 1/3 smog forming volatile organic compounds and oxides of nitrogen in the region (2/3 if include non-road engines)
- Are the primary source of carbon monoxide
- Emit 80-90% of four priority toxic compounds on a regional average

Direct mobile source emissions:

Regional Average:

	On-road	Non-road
Acetaldehyde	30%	70%
Benzene	54%	46%
1,3-Butadiene	67%	33%
Formaldehyde	40%	60%
Particulate matter	82%	18%

KSC Inventory assessment—Non-road Engines

- Non-road motor vehicle sector is expected to replace the on-road sector as the largest source of air toxic emissions from the mobile sector by 2008.
- Non-road gasoline and diesel vehicles and equipment are the dominant source of primary acetaldehyde and formaldehyde emissions (72-90%) in both rural and urban states in the Northeast.
- Non-road diesel engines are projected to contribute up to 70% of the total mobile source particulate emissions by 2010.

KSC Inventory assessment—Non-road Construction Equipment

Construction equipment in the Northeast emits 10% of all nitrogen oxides. Precursors to ozone and secondary fine particles.

Construction equipment in the Northeast emits 33% of all mobile source $PM_{2.5}$. This is particularly challenging in urban areas.

In the Northeast alone, approximately 48,000 - 200,000 employees are believed to be exposed daily to diesel exhaust concentrations from construction equipment activities.

The Multiple Air Toxics Exposure Study II

- Monitored 30 toxic air pollutants at 24 sites
- Conducted a computer dispersion modeling study (included emissions inventory development)
- Estimated the risk of developing cancer over a lifetime of inhalation exposure

Reference: South Coast Air Quality Management District, November, 1999.

The Multiple Air Toxics Exposure Study II

Findings:

- **Diesel soot accounted for 71% of the cancer risk,**
- **1,3 butadiene 8% of the risk,**
- **benzene 7%,**
- **carbonyls 3%, and**
- **others (primarily from stationary sources) 11%.**

Led to AGGRESSIVE diesel (on-road and non-road) emissions control---state and local air quality control

KSC Exposure Assessment for Petroleum Diesel in Non-Road Sector

Goals for our early work:

- To evaluate occupational exposures and environmental impact of nonroad diesel equipment activity
- To qualify (and to the degree possible quantify) health risks for exposed populations

Project Timeline

- Project initiated April 2002.
- Final field monitoring completed May 29, 2003.
- Final report released to USEPA February 2004.

Monitoring Sites

- Construction sites in Keene and Manchester, New Hampshire,
- a lumberyard in Maine,
- a Vermont dairy farm, and
- a New York City construction site (World Trade#7).


436 B
JCB


CAT
D6R
CATERPILLAR


CAT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CAT


FALCO


CAT
BENCOM 4


JOHN DEERE
FORD

Conclusions

In all five locations, diesel equipment activity substantially increased* fine particulate matter exposures.

*Average concentrations were 1-16X greater than normally recorded in each area.

Conclusions

In all five locations, diesel equipment activity increased* diesel particulate matter exposures.

*Other projects have concluded that, in an urban environment, diesel particulate “background” ranges between 0.4 – 1.5 $\mu g/m^3$. These data demonstrate that nonroad equipment activities will increase these concentrations by 1 - 6 X.

Conclusions

- Concentrations of several monitored gaseous pollutants are several hundred times greater than carcinogenic risk screening thresholds
- Concentrations of toxic metals vary across sites and in some cases exceed established allowable exposure concentrations.

Conclusions

- Occupational exposures to $PM_{2.5}$ for operators of the diesel equipment ranged from 2 to over 660 $\mu g/m^3$ (well below the ACGIH/OSHA standards).
- At the higher end of this range, exposure levels are more than 10 times above the national (EPA) ambient air quality standard.
- Diesel particulate matter concentrations shown to exceed the establish reference concentration in numerous instances.

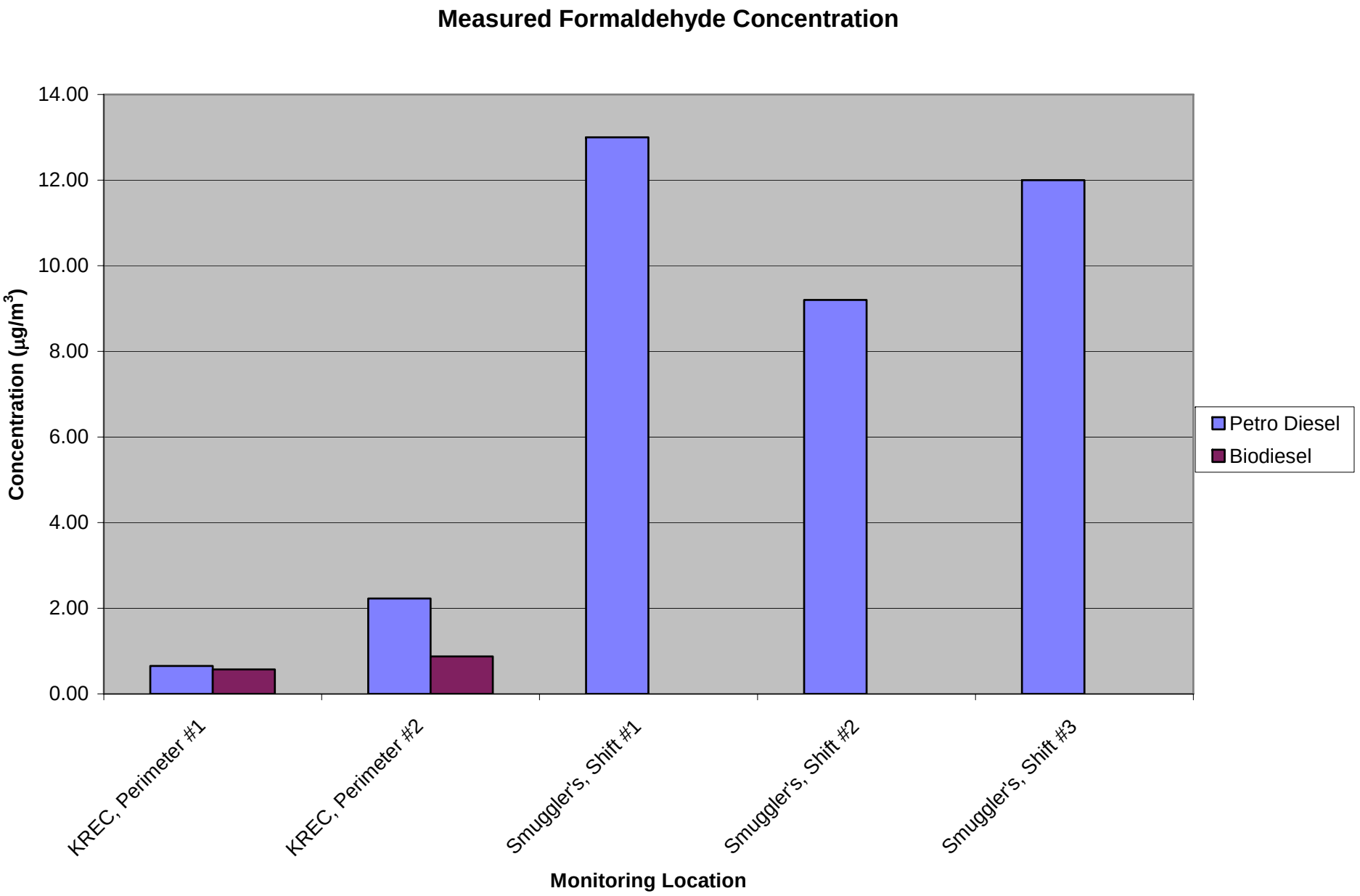
What about Stationary Source Engines burning Petroleum Diesel?

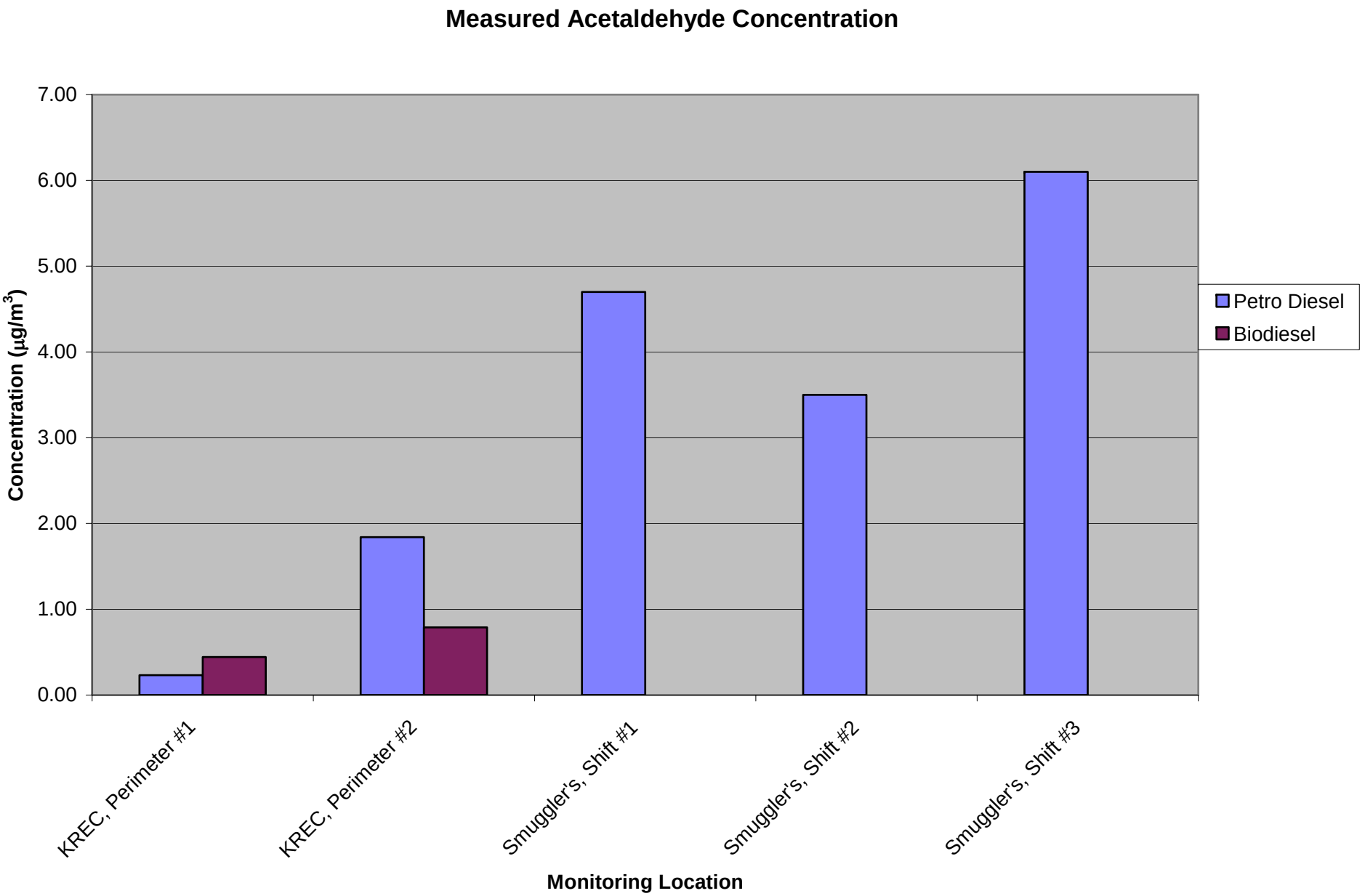
Measured *Average* Fine Particulate Matter Concentration

Location	8-hour Average Concentration ($\mu g/m^3$)
Keene Recycling Center	95
Smuggler's Notch, Shift #1	400
Smuggler's Notch, Shift #2	220
Smuggler's Notch, Shift #3	110

EPA requires a 24-hour fine particulate matter exposure of less than 35 $\mu g/m^3$

Our Smuggler's Notch 24-hour average was 243 $\mu g/m^3$


Measured Formaldehyde Concentration
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Concentration (µg/m3)
Petro Diesel
Biodiesel
KREC, Perimeter #1
KREC, Perimeter #2
Smuggler's, Shift #1
Smuggler's, Shift #2
Smuggler's, Shift #3
Monitoring Location


Measured Acetaldehyde Concentration
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Concentration (µg/m3)
Petro Diesel
Biodiesel
KREC, Perimeter #1
KREC, Perimeter #2
Smuggler's, Shift #1
Smuggler's, Shift #2
Smuggler's, Shift #3
Monitoring Location

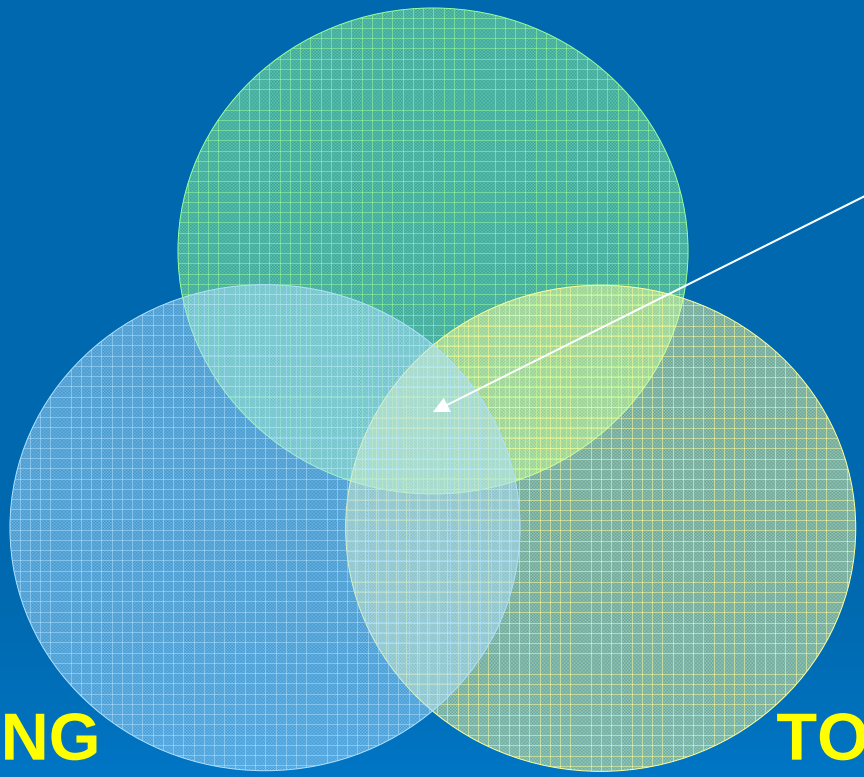
Why not await the pending federal requirements?

- Phase in for nonroad emission controls 2008 and 2014.
- New fuels and engine technologies likely not in the field for years - decades to come.
- Current challenges with ultra low sulfur diesel for on-road engines and engine technology delays (2007 standards) will be a problem…
- After market emissions controls, cleaner fuels, or other emission reduction efforts focused on the current fleet will mean exposure reductions and environmental improvement immediately.

Biodiesel emissions (compared to petroleum diesel)

Pollutant	**B100**	**B20**
Hydrocarbons	-80-90%	-21%
CO	-40%	-11%
Particulate Matter	-30-50%	-10%
NOx	+12%	+2%
Sources:	www.biodiesel.org www.epa.gov	

LOCAL DECISION-MAKING & POLICY

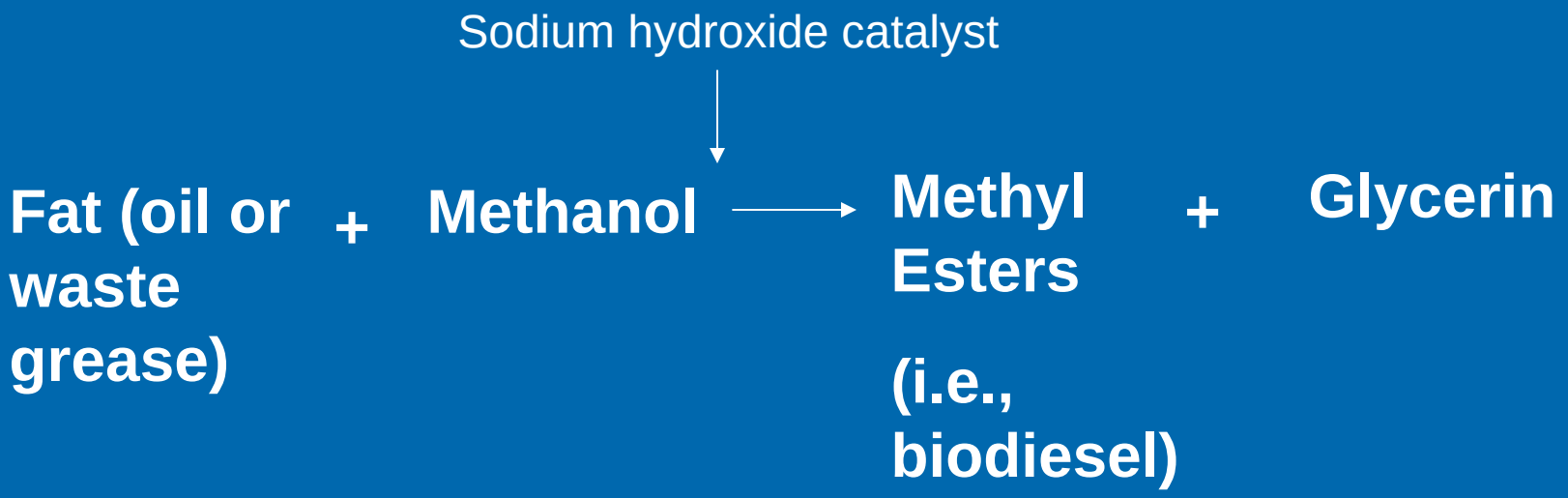


First…a quick review – What is Biodiesel?

Biodiesel = methyl esters made from vegetable oil or waste grease

- **Low toxicity**
- **Biodegradable**
- **Renewable**
- **Made from vegetable oil (Soy, rapeseed, canola, African oil palm) *or* waste grease or animal fat**

Transesterification



Making biodiesel is similar to making soap – except methanol and sodium hydroxide need special attention for safe storage and handling

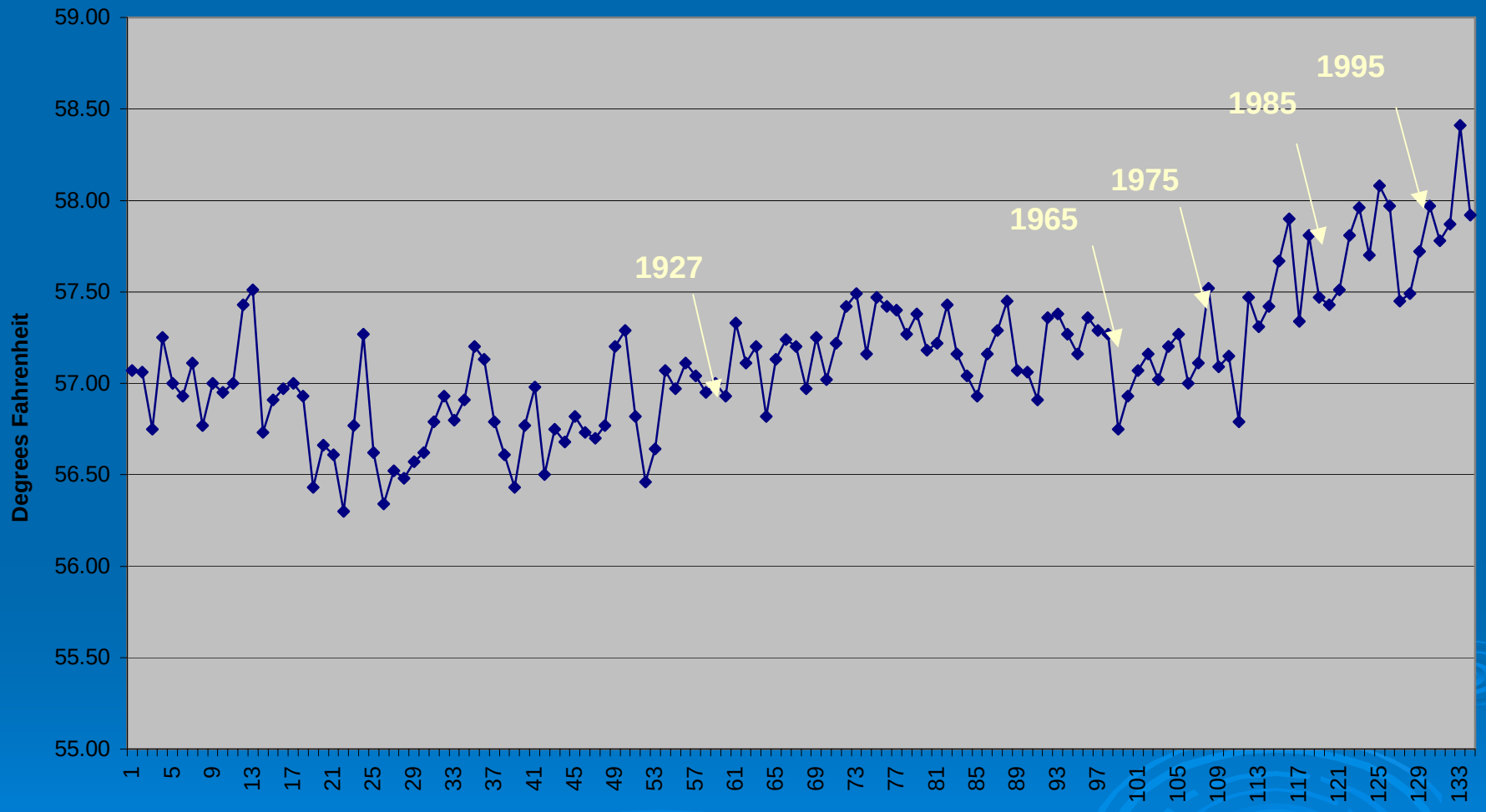
The original diesel engine

Henry Ford in 1941: Taking an axe to his renewable car made of soy based plastics & hemp

If biodiesel is the answer….

What's the question?

Average Global Temperature (1866 - 1999)



Source: Hansen, J. et al., Goddard Institute for Space Studies, Table of Global-mean Monthly, Annual, and Seasonal Temperatures

Political & economic arguments for biodiesel

- Need for renewable energy
- Decreases U.S. reliance on foreign oil
- Increases jobs in agricultural & manufacturing sector

What do people in Keene think?

- 50% of respondents supported biodiesel use in Keene because it is “good for the environment”.
- 37.5% supported biodiesel use to “reduce dependence on foreign oil”
- 100% think biodiesel is “healthier”…but 89% believe more research is needed to understand biodiesel’s “risks/benefits”
- Cost, while not a major issue with the Keene group, is also not a non-issue

Keene State College

- Using biodiesel since 2002
- Garbage truck, snow plows, dump trucks, lawn mowers, bobcats, front end loaders, & tractors
- Grounds staff reported less headaches, less nausea, less eye & respiratory irritation

City of Keene

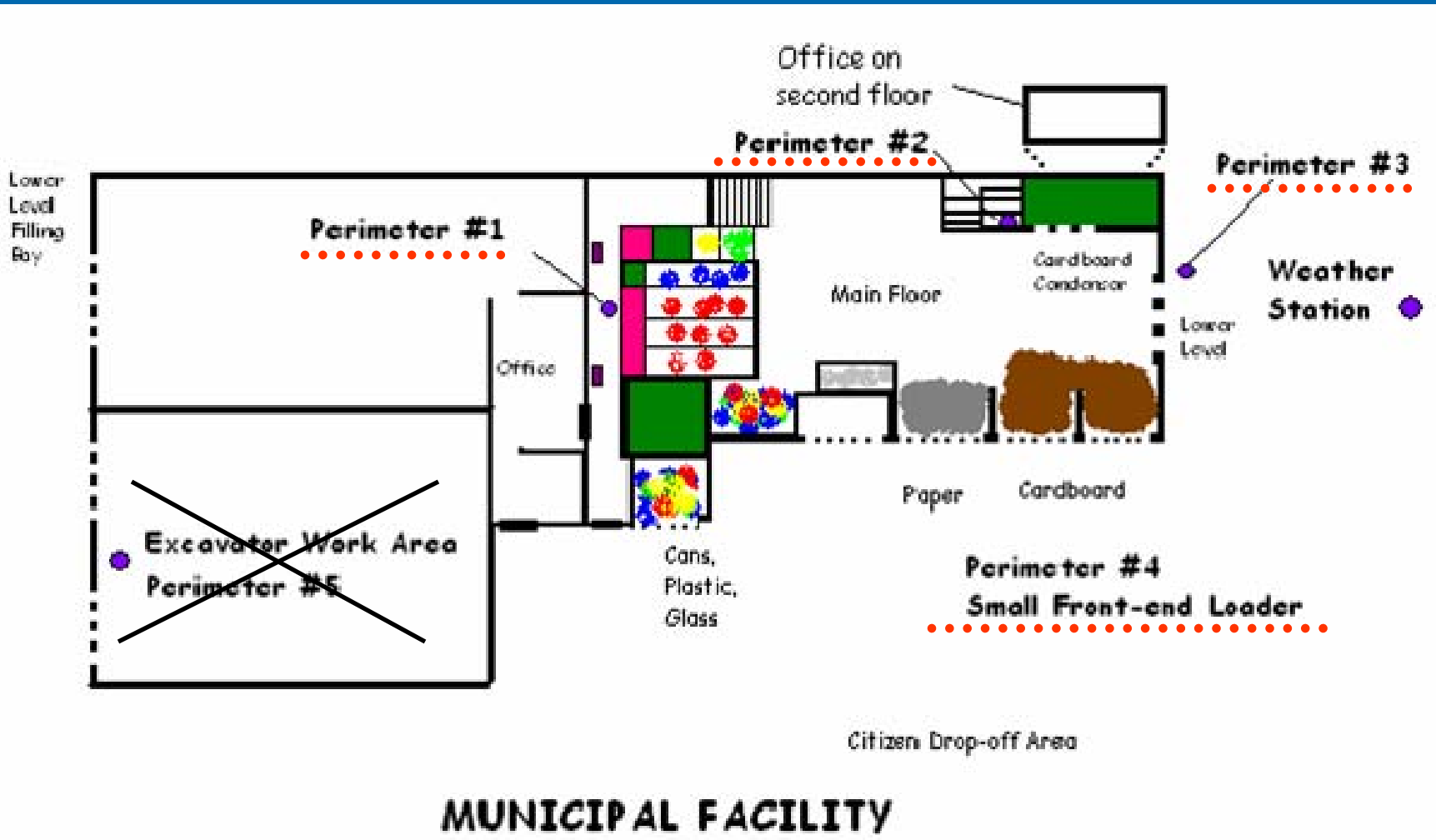
- Also began using in 2002
- Dedicated a 20,000 gallon UST
- Use in 150+ vehicle fleet
- Employees reported less headaches, less nausea, less eye & respiratory irritation
- This John Deere is from Recycling Center

The KSC/City of Keene Collaboration: Research Project Outline

- Mixed methods research
  - Connected the resources at Keene State to the questions posed by the City of Keene to perform a collaborative exposure assessment
  - Case study approach for decision-making related to biodiesel

- Over the summer of 2006 we spent four weeks at the Keene Recycling Center conducting environmental air monitoring in operator work zones and in the local environment.
  - Ten days of the study, equipment was running on petroleum diesel.
  - Eight days of the study, equipment was running on 20% biodiesel (B20).

Keene Recycling Center

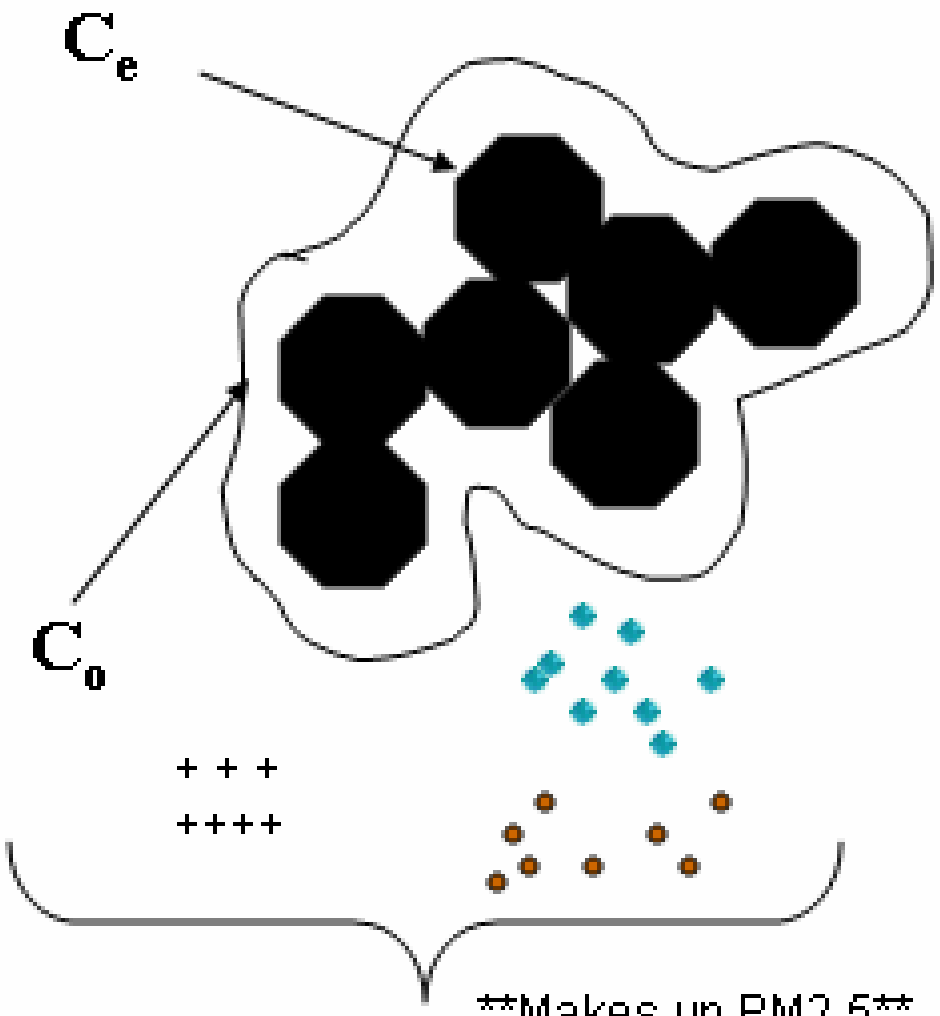


Central Question?

- Does B20 use result in lower emissions of:
  - PM2.5;
  - Elemental/Organic Carbon;
  - Oxides of Nitrogen; and
  - Toxic metals of interest?

We employed state of the art occupational and environmental exposure monitoring methods

Diesel Particulate Matter



Total Carbon C_t =

C_e (60-70%) + C_o (30-40%)

Elemental carbon – core with high surface area
Organic carbon – adsorbed hydrocarbons which can include mutagens, carcinogens

+ Inorganic gas particulate

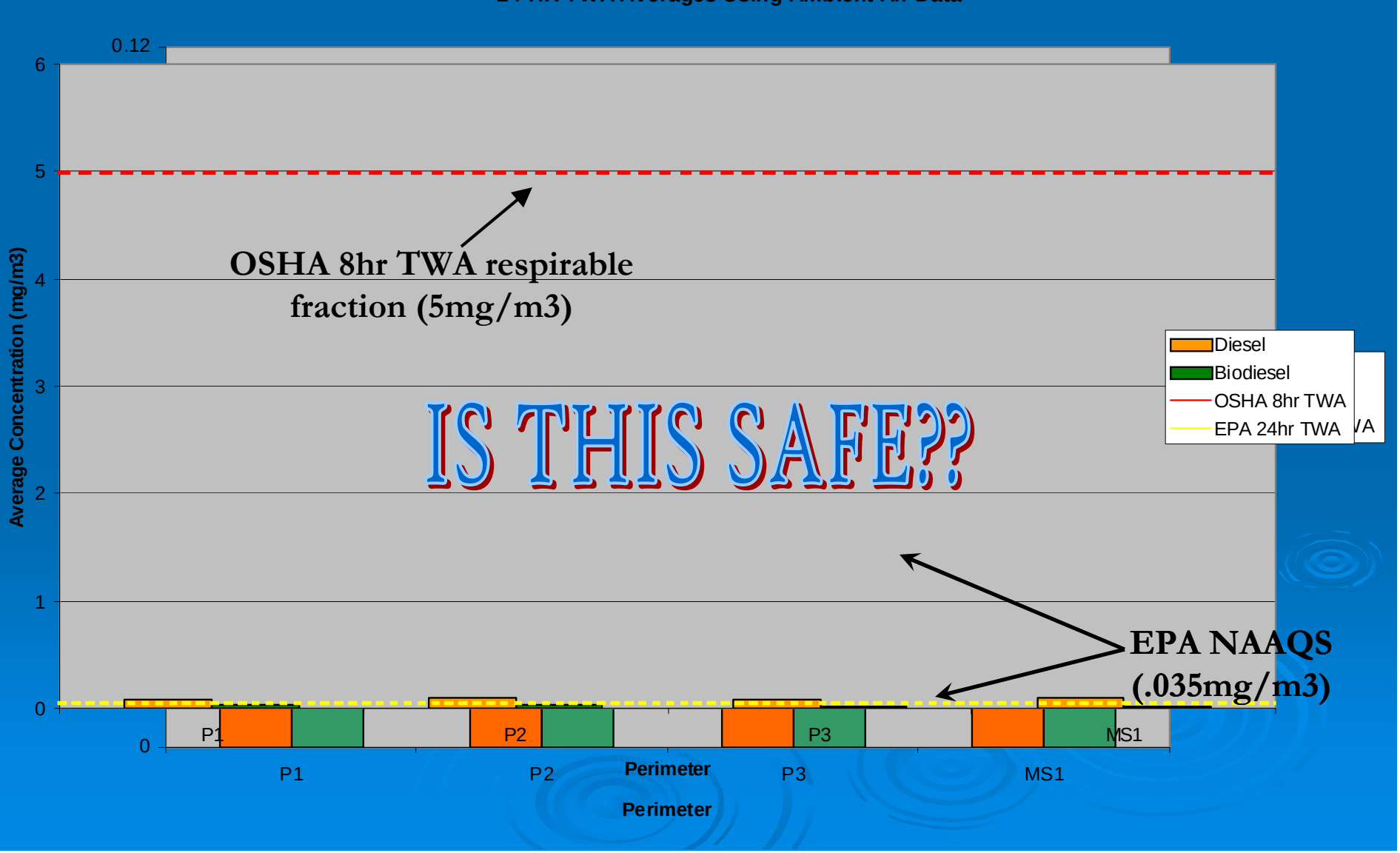
NO_3, SO_2

+ Hydrocarbons (droplets)

+ Metals

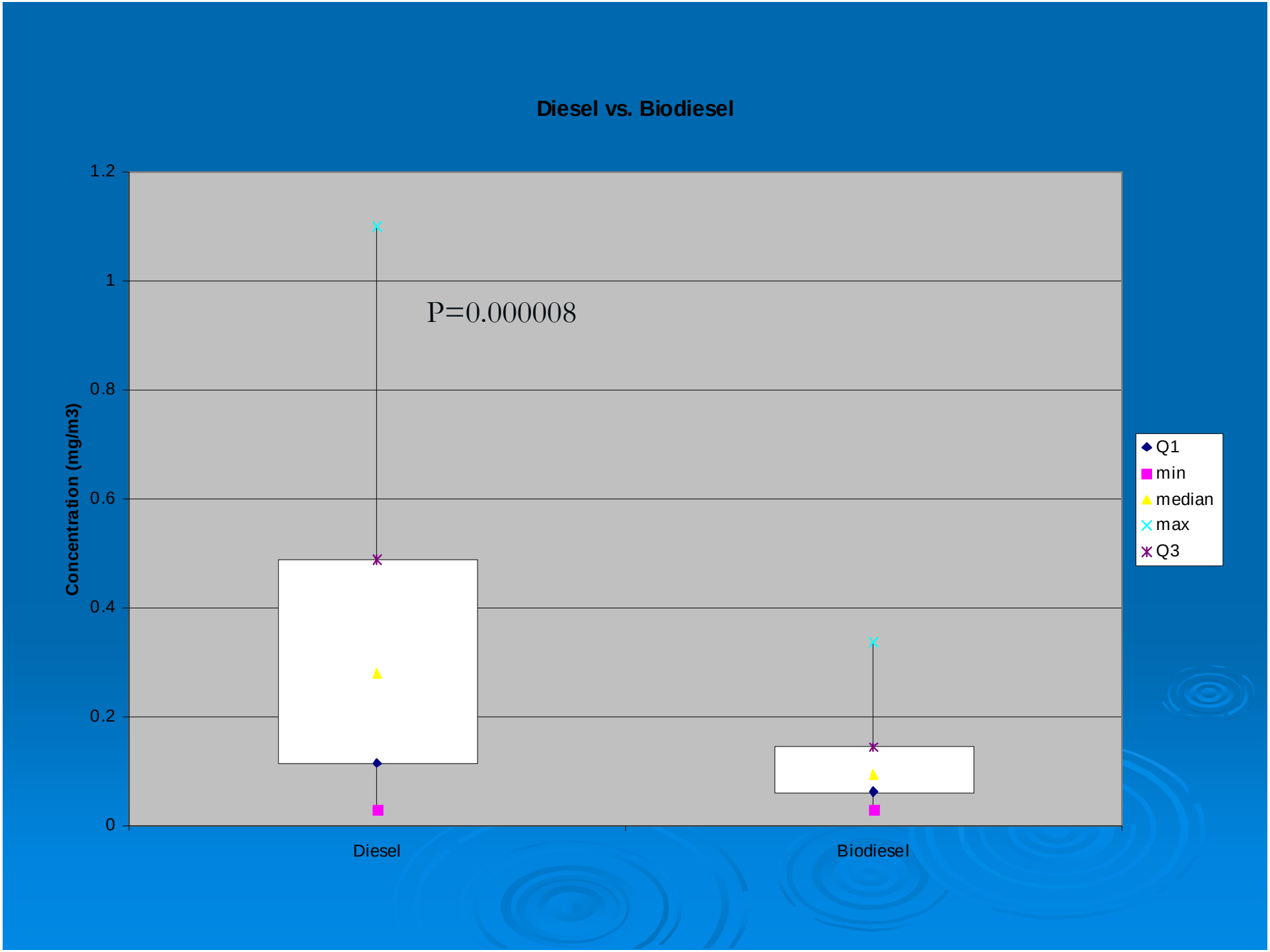
Air Monitoring Equipment

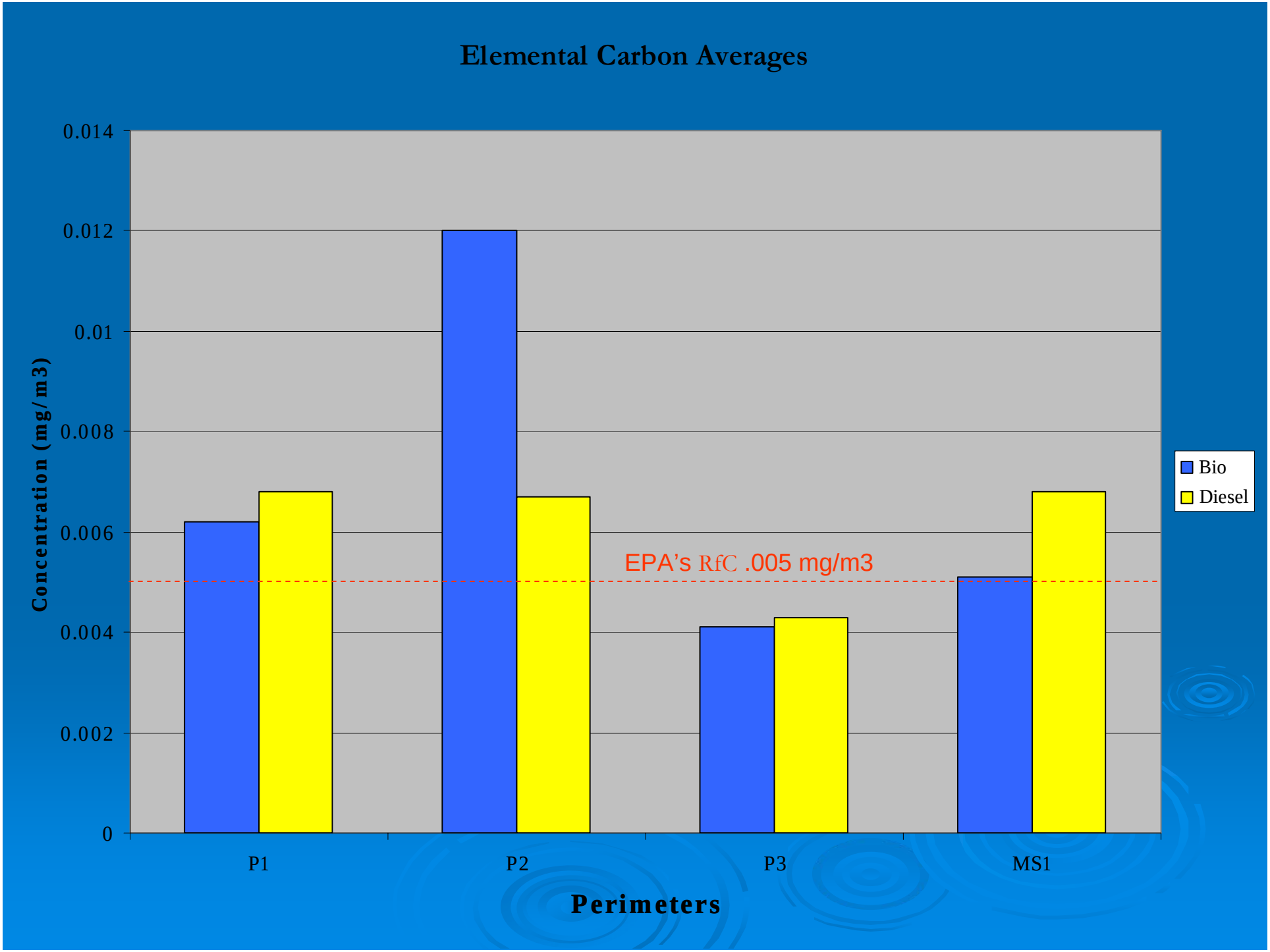
Some Preliminary Results

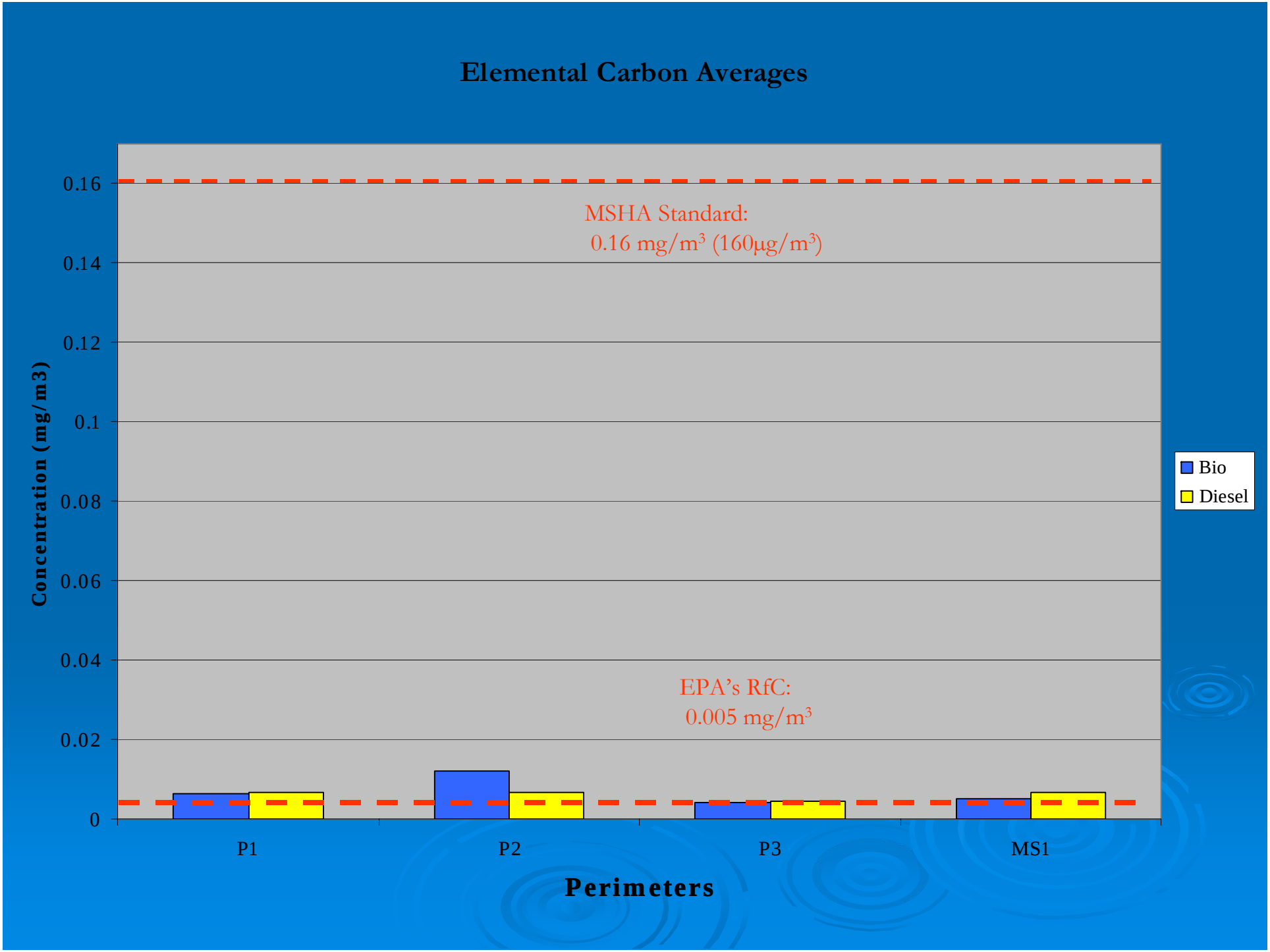


More Results

- PM2.5 reductions by perimeter during Biodiesel weeks
  - P1 – **57.62%**
  - P2 – **64.65%**
  - P3 – **74.12%**
  - Mobile Source 1 – **70.28%**
  - Total Average Reduction – **66.5%**


Diesel vs. Biodiesel
1.2
1
0.8
0.6
0.4
0.2
0
Concentration (mg/m3)
P=0.000008
Diesel
Biodiesel
Q1
min
median
max
Q3


Elemental Carbon Averages
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
Concentration (mg/m3)
EPA's RfC .005 mg/m3
Bio
Diesel
P1
P2
P3
MS1
Perimeters


Elemental Carbon Averages
MSHA Standard:
0.16 mg/m3 (160µg/m3)
EPA's RfC:
0.005 mg/m3
Concentration (mg/m3)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
P1
P2
P3
MS1
Perimeters
Bio
Diesel

Results

- Elemental Carbon changes at various monitoring location during Biodiesel weeks

- P1: - 9%
- P2: + 44%
- P3: - 5%
- Mobile Source 1: - 25%
- Total Average Change: + 12%

Results

- Organic Carbon increases at various monitoring locations during Biodiesel weeks
  - P1: 75%
  - P2: 92%
  - P3: 69%
  - Mobile Source 1: 76%

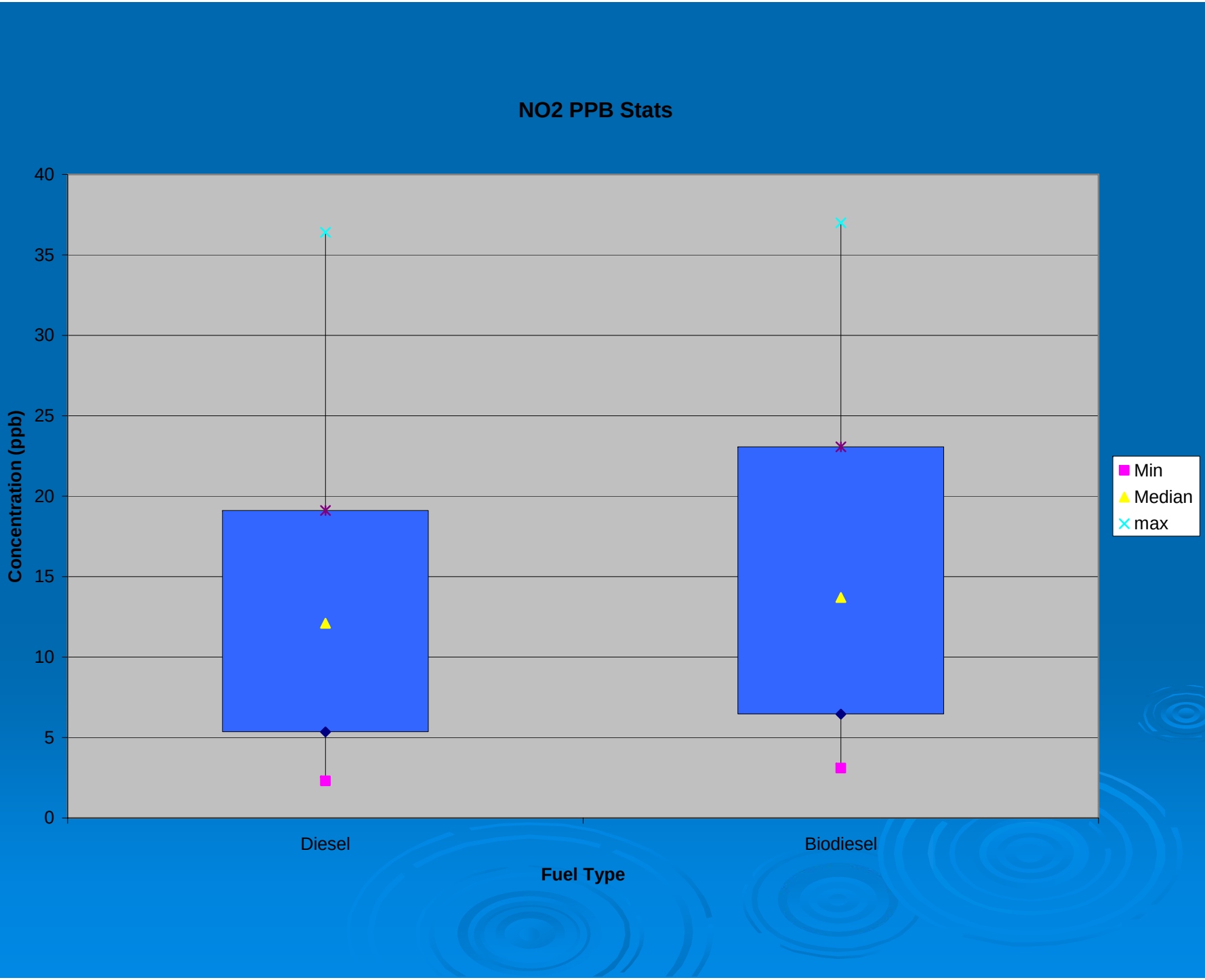
Total Average Increase: 78%

Nitrogen oxides - NOx

- NOx is an ozone precursor and Clean Air Act criteria pollutant
- NOx leads to the formation of ground level ozone and smog

Sunlight + NOx + VOC's + heat = smog

Many scientists are concerned about the impact of biodiesel on NOx. An EPA study (2002) indicated NOx should increase with increasing % biodiesel in the blend. Other scientists report the opposite – the "perfect storm" of policy controversy.


NO2 PPB Stats
Concentration (ppb)
40
35
30
25
20
15
10
5
0
Diesel
Biodiesel
Fuel Type
Min
Median
max

DRAFT Conclusions to Date

- B20 use appears to cause a statistically significant decrease in PM2.5 concentrations
- B20 use appears to cause a statistically significant increase in Organic Carbon concentrations

DRAFT Conclusions to Date

- B20 use does not appear to cause a statistically significant change in NO_2 concentrations

- B20 use does not appear to cause a statistically significant change in Elemental Carbon concentrations

Case Study - discussion

- 2006 - Formed Biodiesel Working Group
- Initial goal: to discuss the research and communicate results to community
- 2007: Where does BWG go from here?
- Community education? Additional research?
- Next decision-making steps…increase use? Local supply?

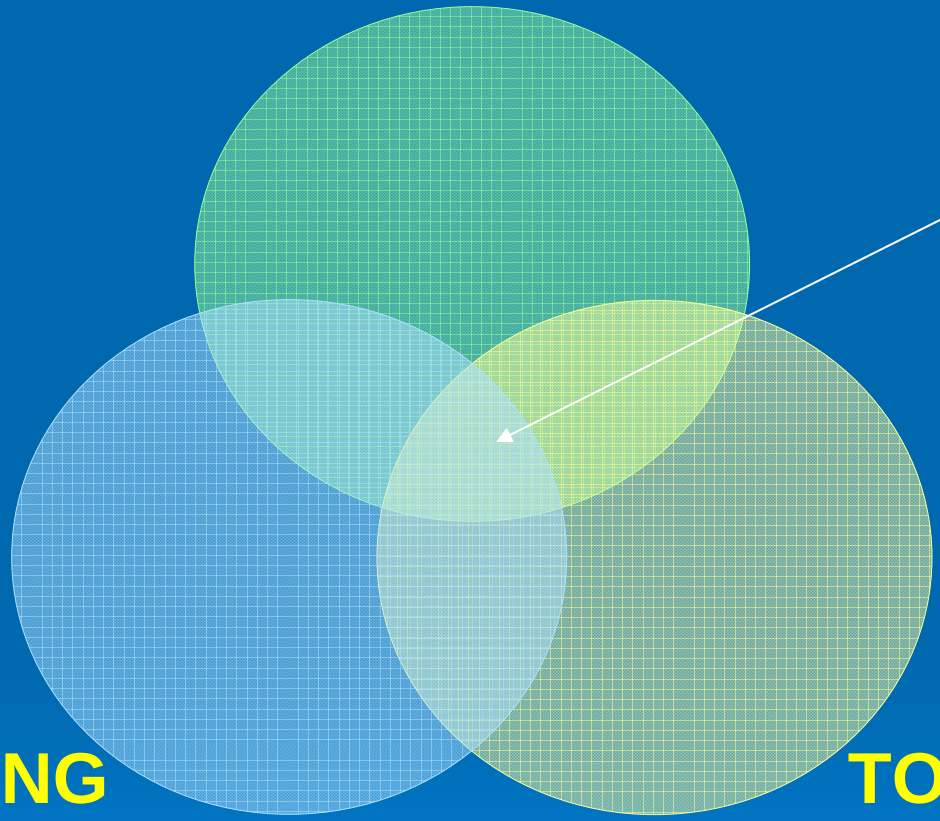
Biodiesel education still needed in Keene

- 35% of respondents believe that biodiesel is simply adding vegetable oil to diesel
- 52% either didn't know or thought biodiesel use increases NOx
- 44% either didn't know or believed using biodiesel could void an engine's warranty
- 44% either didn't know or thought biodiesel supply could meet petroleum demand

Future Questions

- How do we best inform local policy with this new research data?
- What are the changes in PM composition with biodiesel use---particularly OC?
- How do we overcome local supply barriers?
- Are there differences between mobile and stationary source emissions with biodiesel?
- PM2.5? Is B20 the equivalent of 2007 standards?

DECISION-MAKING & POLICY



ENGINEERING

TOXICOLOGY

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Brendan McDuffee

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